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RESPONSE OF ICELANDIC SOILS TO GRAZING EXCLUSION

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ABSTRACT

Grazing exclusion is a common practice for restoration of degraded rangelands. A study was carried out on common grazing lands of Iceland at Audkuluheidi and Theistareykir, to assess the effect of short-term grazing exclusion on different soil properties. Soil samples were collected inside and outside grazing exclosures at two depths (0-5 and 5-10 cm). Soil pH, organic matter content and C:N ratios were analysed for each plot. With reference to the fenced plots, there were no significant differences in soil chemical properties between the two sites but local differences between habitats (gravel desert and heath) are reported. The results point to the fact that the practice of grazing exclusion has no effect on the soil chemical properties in the short term. Long term monitoring in these areas could inform about the minimum time needed to detect differences between fenced and non-fenced areas, to report on the optimal exclusion duration for soil recovery in Icelandic rangelands. Such studies would provide valuable information on the conservation and use of these common grazing lands to a nation with such a rich culture of grazing.

Key words: grazing exclusion, soil properties, rangelands, livestock, degradation.

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ABBREVIATIONS

UNU-LRT	United Nations University Land Restoration Training Programme
GE	Grazing exclusion
LOI	Loss on ignition
SOM	Soil organic matter

1. INTRODUCTION

Livestock grazing is the largest land use in the world, and it has unquestionable effects on the environment including influences on vegetation, wildlife and the functioning of natural processes (Chen et al. 2017). Over 80 percent of agricultural land globally is dedicated to livestock production with 3.4 billion hectares used for grazing and 0.5 billion for feed crops (FAO Statistical Pocketbook 2015). In Iceland, sheep grazing constitutes an important component of its agricultural system dating back to 1100 years ago when the island was first settled (Marteinsdóttir et al. 2017). In the early days and up to the 18th century, sheep numbers were relatively low, linked to limited access to winter feeding since fodder harvesting was still limited at the time and most supplementary feeds were used for the dairy cattle (Thorhallsdóttir et al. 2013). Open winter grazing naturally limited sheep stocks, a trend which changed with improvement in technology and hence the ability to cultivate fodder (Ross et al. 2016). Since then, the numbers of sheep in the country have been on the rise, from 300,000 animals at the turn of the 20th century to over 600,000 only 50 years later with a record high of 960,000 sheep in the 1970s (Arnalds & Barkarson 2003).

With the high numbers of sheep came degradation of the fragile highland rangelands with reports of increased incidences of erosion and deteriorating vegetation cover (Arnalds 2015) as is often the case in common rangelands (Abdalla et al. 2018). In Uganda, for example, management of rangelands has for a long time been in the hands of tribes who own the grazing rights based on the needs of the individual communities. The rate of degradation of these lands has been on the rise as a result of no incentive for individuals to maintain them (Byakagaba et al. 2018). It has become a common practice for farmers to abandon degraded rangelands for better grazing areas, sometimes many miles away (Kariuki et al. 2018).

Attempts to restore degraded lands have been ongoing, one of which has been grazing exclusion where livestock is kept away from severely degraded lands to allow for their recovery (Arnalds & Barkarson 2003). Grazing exclusion not only removes the degradation driver to facilitate self-repair of the system but can also be applied at broad spatial scales (Wang et al. 2018). Exclusion has further been linked to several environmental benefits including increased vegetation cover (Zhao et al. 2019) and improved nitrogen and carbon stocks in the soil (Sato et al. 2019). In addition, the popularity of the practice is also because of the little financial investment involved (Wang et al. 2018) but with potential benefits to nature and society (Albert et al. 2017). Whether grazing exclusion can be promoted as a management option for degraded rangeland soils in Iceland remains an open question, since grazing research in the country has mainly focused on vegetation and to a lesser extent on soils and soil fauna (Marteinsdóttir et al. 2017). Elsewhere, research on changes in specific soil parameters associated with soil health in response to grazing exclusion has reported conflicting results. For example, some studies have reported higher soil pH in grazed areas due to addition of urine (Raiesi & Riahi 2014). As well, grazing exclusion has been linked to improved nitrogen and carbon stocks in the soil (Sato et al. 2019). Other studies, however, report reduced rates of carbon and nitrogen cycling (Gao-Lin et al. 2017). Relatedly, soil organic carbon increased in an exclusion study in the Zagros Mountains of central Iran (Raiesi & Riahi 2014) but decreased in a study of a montane pastureland on the northern Tibetan plateau (Shi et al. 2013), whereas no change was reported in an upland grassland in northern England (Medina-Roldán et al. 2012) or in a semi-arid sage brush steppe in USA (Shrestha & Stahl 2008).

Contrasting responses to the practice of grazing exclusion can be attributed to differences in grazing exclusion periods, climate, topography and soil type (Li et al. 2016). Icelandic soils, for example, have unique properties due to their volcanic origin. These soils, Andosols, are rich in nutrients but lack cohesion, so they are especially vulnerable to erosion. They are also modified regularly by fluxes of aeolian materials especially for places close to the deserts (Arnalds 2015). The aeolian materials have an influence on soil pH through the weathering of tephra with higher pH values at places closer to the source of the materials (Arnalds 2010).

Although information on the effects of grazing exclusion exists, it is difficult to draw conclusions and integrate the findings from the various studies as they are often contradictory. Our current understanding of grazing exclusion on soils is therefore not complete. This lack of knowledge impacts our ability to direct landscape processes and assess the practice as a management option. Here, I used a site-specific assessment of key soil chemical properties in a field experiment in Iceland and report on the response of different soil types to grazing exclusion. Since exclusion is a practice embedded in the cultures of many farmers, reporting on the response of specific soils would not only improve our understanding of the practice but also aid in identifying further management options following grazing exclusion. The results of this study will therefore inform decisions on whether to exclude or retain livestock in degraded areas but also provide a framework for communicating the benefits of grazing in some areas and not others. Also, the study provides a basis for comparison with related studies that have been done in similar or different environments.

1.1 Objectives of the study

The overall objective of the study was to quantify the effect of grazing exclusion on soil properties in selected Icelandic highland habitats that are traditionally used as summer rangelands. An assessment was made of the magnitude and direction of change of different soil properties following 3 years of grazing exclusion at sites within and outside the volcanic active zone, in areas with contrasting vegetation cover.

1.2 Research questions

i. Do soil properties differ inside and outside the volcanic active zone?
ii. Do soil properties differ in habitats with contrasting vegetation cover?
iii. Does grazing exclusion affect soil properties? If so, a) which soil properties (pH, soil organic matter and C:N ratio) are more responsive to grazing exclusion? And b) does the effect of exclusion on soils differ between sites inside and outside the volcanic active zone and between habitat types?

1.3 Justification of the study

The study provided an opportunity to identify further management options following grazing exclusion. Also, the measurement of different soil quality indicators provides a link between science and practice and the results can be used in assessing the sustainability of the management practice.

2. METHODS

2.1 Description of the study area

The study was carried out at two sites in the Highlands of Iceland; Audkuluheidi (65°13'N, 19°67'W), outside the volcanic active zone, and Theistareykir (65°89'N, 17°08'W) inside the volcanic active zone (Fig. 1). Audkuluheidi is in central Iceland with soils classified as andosols (Arnalds & Óskarsson 2009). Theistareykir on the other hand is in north-eastern Iceland, much closer to the coast than Audkuluheidi. Hence, both sites differ slightly in climatic conditions resulting from the different elevations (340 m compared to 490 m for Audkuluheidi). The soils in Theistareykir are classified as well drained andosols and are geologically younger than those outside the active volcanic zone (Arnalds, 2015). The two sites are summer grazing areas used for extensive sheep grazing, with a long history of grazing use.

2.2 Experimental design

In spring 2016, a grazing exclusion experiment was set up at each study site, in two different habitats with contrasting vegetation cover; a dwarf shrub heath (nearly 100% vegetation cover) comprising *Betula nana, Empetrum nigrum, Vaccinium uliginosum* and *Silene acaulis,* and a gravel desert (5-10% vegetation cover) with vascular plant species like *Armeria maritima, Cerastium alpinum, Arabidopsis petraea* and *Juncus trifidus.* These habitats originally had similar topography, soil properties and vegetation cover that later changed due to soil erosion and land degradation of some areas. Thus, the two habitats represent two extremes of a degradation gradient, with the gravel desert being a degraded ecosystem and the heath representing a healthier ecosystem.

This study is thus part of a long-term study with replicated plots and randomly assigned treatments established for monitoring of ecological effects of grazing (Fig. 2). In each of the study sites, two different habitats were targeted, a gravel desert and heath (Fig. 2a). In each habitat at the two study sites, metal fences 1.2 m high were used to exclude grazing from the experimental plots (fenced plots; Fig. 2b). The adjacent areas outside the exclosures remained open to sheep grazing during summer and were therefore defined as control plots (Fig. 2b).

2.3 Soil sampling

Sampling was conducted at the beginning of the summer grazing season in mid-June 2019. Soil sampling was conducted inside and outside the grazing exclosures, along 6 m long transects with three sampling points along each (Fig. 2b). The soil samples were taken up to a depth of 10 cm because most of the roots in the areas are shallow, and hence, changes in soil quality induced by grazing exclusion would be expected mainly in this zone. Using a soil corer of diameter 2 cm, three individual soil samples were taken from 0-5 and 5-10 cm and pooled to obtain two composite samples (one per depth) of each plot. In total 96 samples were collected (2 study sites x 2 habitats x 6 plots x 2 treatments x 2 depths). Samples were then transported in coolers to the Soil Conservation Service of Iceland for analysis.

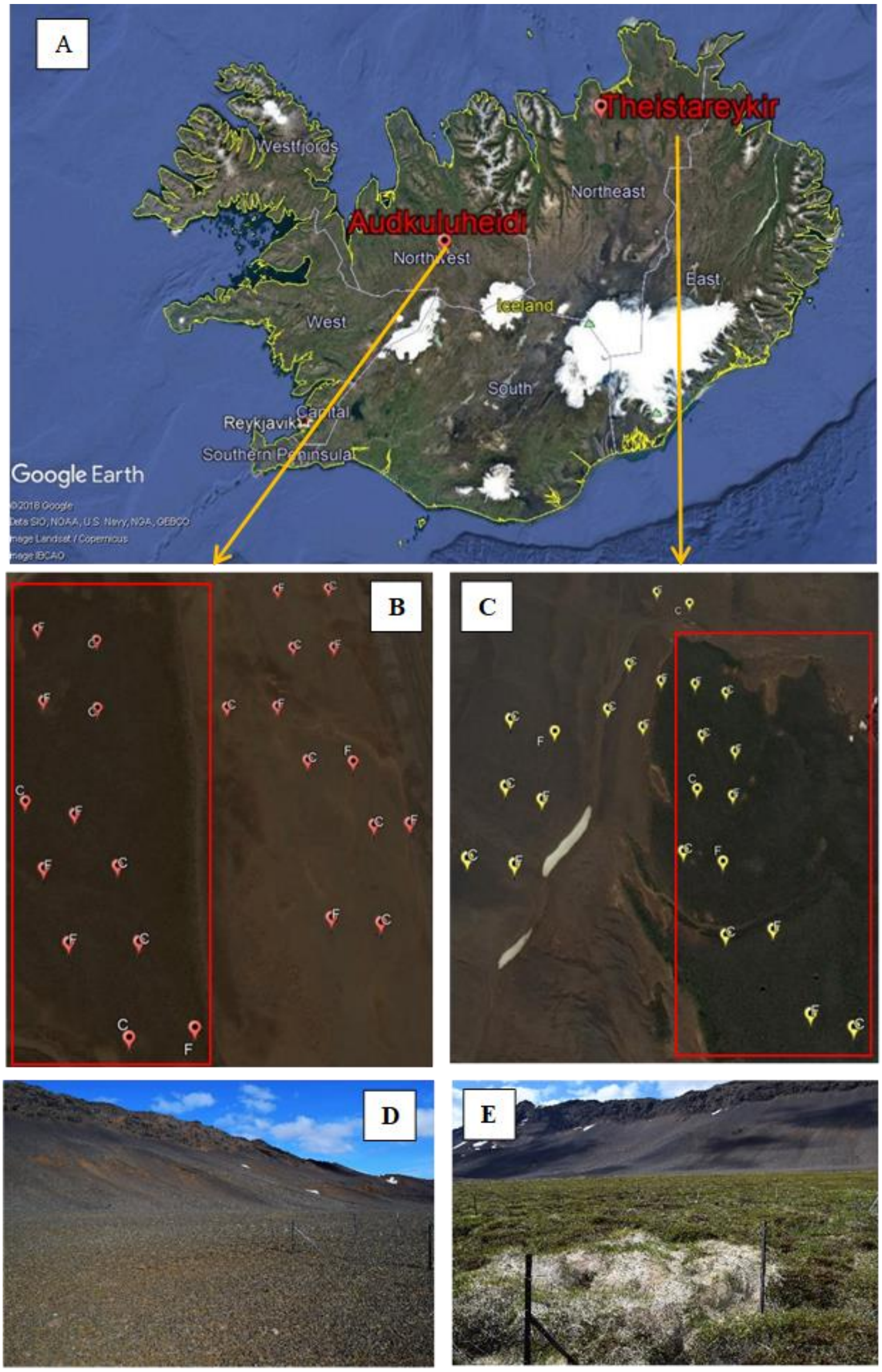

Figure 1. Location of the study sites (A) and the location of the experimental plots at each site (Audkuluheidi (B) and Theistareykir (C)); vegetated areas in red boxes, letters overlaying the points indicate fenced (F) and control (C) plots) in areas with contrasting habitats, a gravel desert (D) and a well vegetated heath (E). Images obtained from http://maps.google.com and author's own collection.

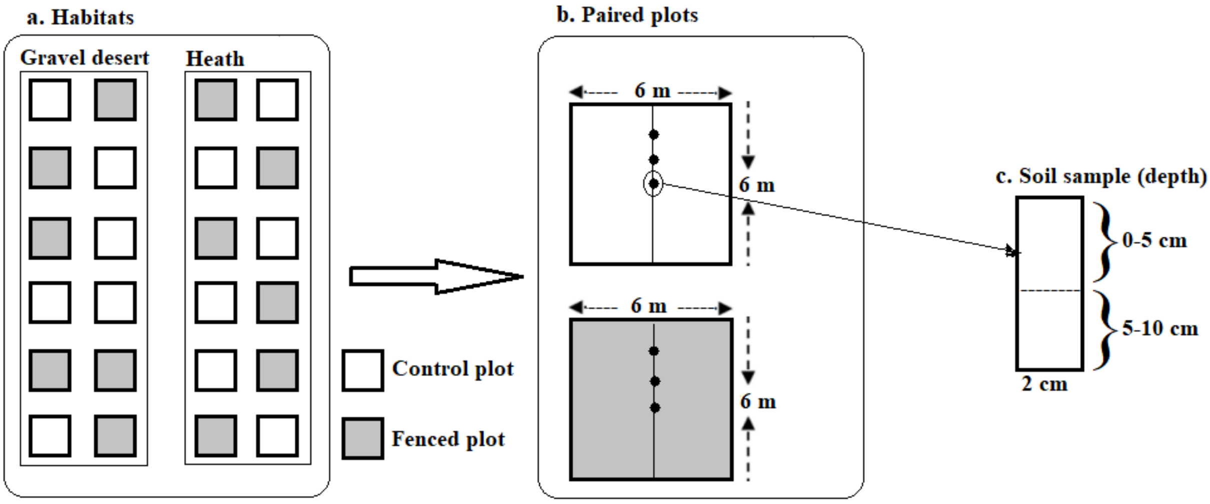

Figure 2. Experimental design for the study denoting (a) six pairs of grazed and fenced plots at each study site in two habitats (only one site represented), giving a total of 24 plots for each site. (b) Soil samples (black dots) were taken 3 m from the edge of the plot, in pairs of fenced and control plots, along a transect, and (c) at two different depths (0-5 and 5-10 cm).

2.4 Determination of soil properties

Prior to analyses, samples were oven dried at 40°C and sieved through a 2 mm sieve to remove plant materials and rocks. The soil was then weighed and stored in 50 ml tubes for further analysis of pH, soil organic matter and C:N ratio.

2.4.1 Soil pH

Five grams of each soil sample (0-10 cm) were weighed into 50 ml tubes in duplicates of each sample. De-ionized water (25 ml) was added to the sample and the mix put in the shaker for 2 hrs and allowed to settle into a supernatant solution. The solution was then used for pH measurements using a pH meter (Oakton| pH| Mv°C, Oakton Company, Australia) with appropriate calibration (using 2 buffer solutions, pH 7.00 and pH 4.00).

2.4.2 Loss on ignition (LOI)

Loss on ignition (LOI) analysis was used to determine the organic matter content of the soil sample (SOM), at two depths (0-5 and 5-10 cm). LOI calculates the content of SOM by comparing the weight of a sample before and after ignition and is expressed as a percentage. Samples were placed in porcelain crucibles (known weight) in duplicates and dried at 105°C for 24 hours and later weighed to the nearest 0.001g. The crucibles containing samples were then heated in a muffle furnace at 550°C for 4 hours. The furnace was allowed to cool to about 105°C (after approx. 2.5 hours). When cooled, the samples were removed from the furnace to the oven and reheated for 1-2 hours at 105°C and weighed out of the oven for their post ignition weight.

2.4.3 C:N ratio

Twenty grams of soil were taken for ball milling to obtain finely ground, homogeneous samples for analyses using direct combustion procedure (Vario EL111, Elementer, Germany) for determination of total C and N concentration. The results from the C:N analysis were then corrected for moisture using values of the dry matter content (Dieckow et al. 2007). C:N ratios were calculated for each sample (0-10 cm).

2.5 Data analysis

Soil properties were compared between sites (inside and outside the volcanic active zone), and between habitats, for control plots (open to grazing) using t-tests. This statistical approach was chosen due to the small sample size. For LOI, where analyses were conducted at two sampling depths, an assessment of the differences between the two layers was done using paired t-tests; if there were differences, analyses for each depth were run separately.

To assess the effects of grazing on soil chemical properties, a comparison of the fenced and control plots was done using paired t-tests. Mean values are reported in the text below together with standard deviations (SD), and significance was assessed at a level of $\alpha = 0.05$. For all analyses the statistical software R was used (R Development Core 2019).

3. RESULTS

3.1 Comparison of soil properties inside and outside the volcanic active zone

The pH values of the soil samples ranged between 5.98 and 7.16, and SOM values ranged between 2.4 and 21.2%. The paired t-test revealed significant differences in SOM between the two sampling depths (paired t-test; t=3.59, p=0.002), with the upper soil layer (0-5 cm) having higher organic matter (mean ± SD: 9.9±5.9%) as compared to the deeper layer (mean ± SD: 7.7±3.5%). Mean C:N ratios were higher inside the volcanic active zone (mean ± SD: 16.93 ± 3.15) compared to outside the volcanic zone (mean ± SD: 15.62 ± 1.48). Soils in Audkuluheidi tended to have higher pH values than those in Theistareykir (t-test; t=2.07, p=0.054; Fig 3; Table A1), but did not differ in terms of SOM (0-5 cm: t-test; t=-0.56, p=0.58; 5-10 cm: t-test; t=-0.14, p=0.89) or C:N ratios (t-test; t=-0.78, p=0.45).

3.2 Differences in soil properties between habitats

A comparison of soil properties between the gravel desert and the heath using the t-test showed a significant difference in the mean pH values in the two habitats (t-test; t= -3.90, p=0.001; Fig. 4; Table A2). Soils in the heath had a lower pH (mean ± SD: 6.48±0.25) than in the gravel desert (mean ± SD: 6.84±0.23). There were large differences in SOM matter between the two habitats, especially in the upper soil layer (t-test; t=9.37, p<0.001) with heath plots having three times more SOM than the gravel desert plots (Table A2). The lower layer (5-10 cm) also showed significant differences in SOM (t-test; t=9.01, p<0.001), with heath plots having two times higher SOM (Table A2). The C:N ratios differed significantly in the two habitats with considerably lower values in the gravel desert plots (t-test; t=4.28, p<0.003, Table 2).

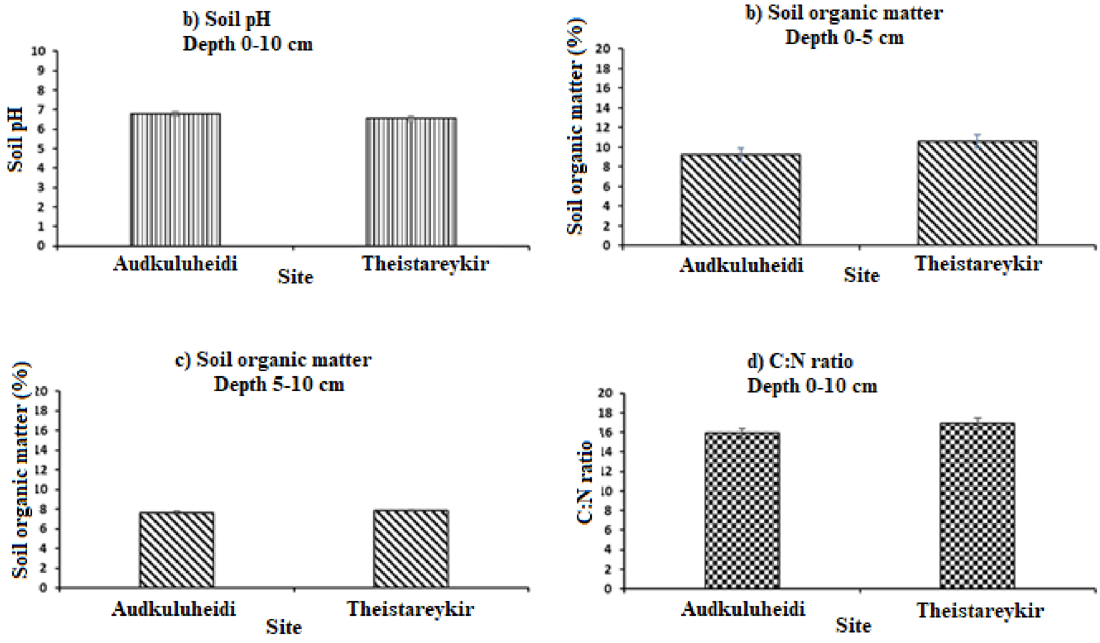

Figure 3. Comparison of the soil chemical properties in the study sites: a) soil pH, b) soil organic matter at 0-5 cm depth, c) soil organic matter at 5-10 cm depth, and d) C:N ratio. Each plot represents mean values of the different soil properties together with the standard error.

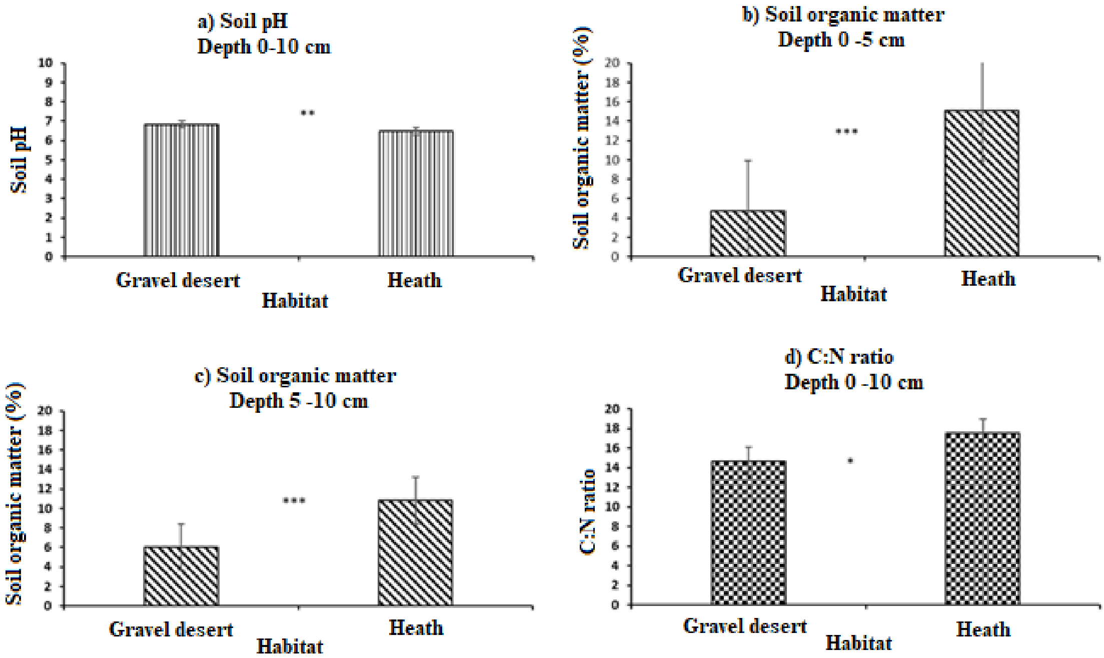

Figure 4. Comparison of a) soil pH, b) soil organic matter at 0-5 cm depth, c) soil organic matter at 5-10 cm depth, and d) C:N ratio in the different habitats (gravel desert and heath). Values represent the mean ± standard error. Asterisks indicate significant differences between habitats (* $p<0.05$; ** $p<0.01$; *** $p<0.001$).

3.3 Effect of grazing exclusion on soil properties

There were no differences between control and fenced plots in terms of pH values (paired t-test; t=0.21, p=0.84; Table 3, Fig. 3), SOM (0-5 cm: paired t-test; t=-0.78, p=0.44; 5-10 cm: paired t-test; t=-0.77, p=0.45) or C:N ratio (paired t-test; t=-1.57, p=0.13).

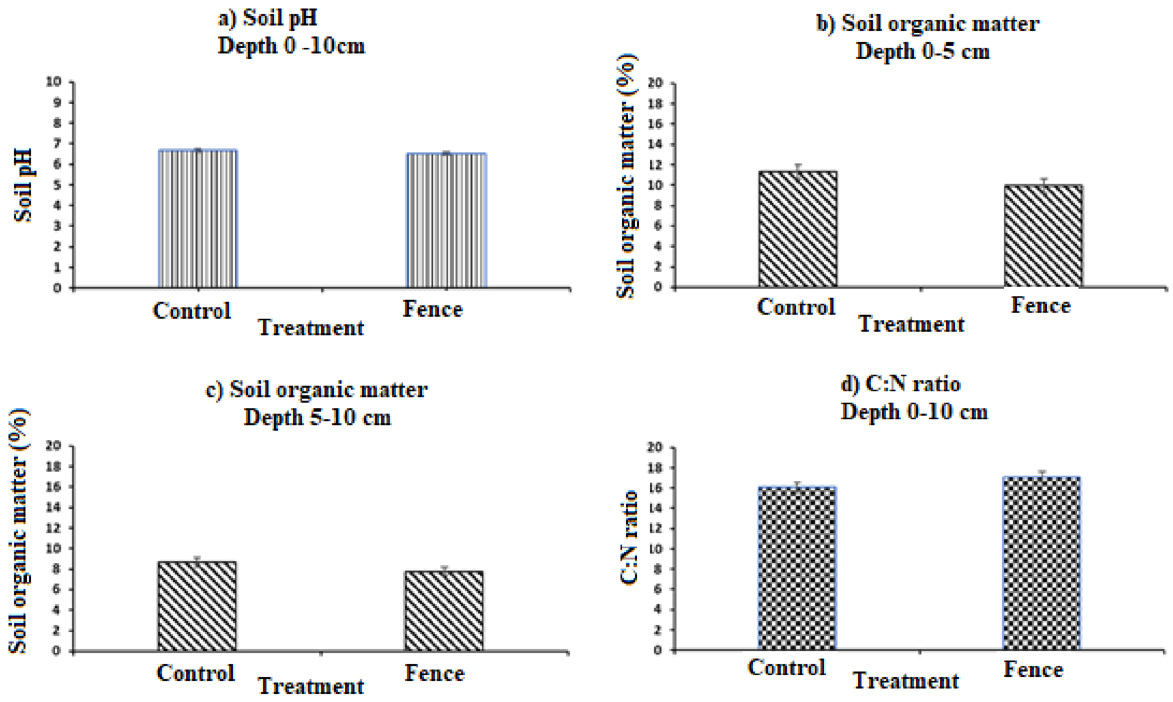

Figure 5. Summary of the effects of the two grazing treatments (control and fence) on a) soil pH, b) soil organic matter at 0-5 cm, c) soil organic matter at 5-10 cm, and d) C:N ratio. Values represent the mean ± standard error.

4. DISCUSSION

In this study, pH, organic matter and C:N ratio were analysed in different habitats and locations to assess the effects of short-term grazing exclusion on soil chemical properties. Overall, the results indicated no significant differences between fenced and control areas in the measured soil properties except in the different habitats, after three years of grazing exclusion.

The pH values at the two sites (Fig. 3) were not significantly different although the expectation was that pH would be higher in the active volcanic zone because of the frequent tephra additions to the soil. This could be because the soils in the two areas are made of the same geological material with similar responses to processes (Arnalds 2015). Besides, changes in soil properties are a very slow process especially with the low temperatures at high altitudes (Jónsdóttir et al. 2005). The higher pH values in the gravel desert as compared to the heath (Fig. 4) could be due to increased erosion because of the poor vegetation cover which exposes the soil profile. Studies have reported lower pH values in vegetated sites with more organic topsoil as opposed to bare surfaces (Mankasingh & Gísladóttir 2019). This is especially true for desert surfaces where the effects of the strong winds are very destructive. Higher pH values have also been reported in grazed areas due to addition of urine (Raiesi and Riahi 2014). The non-significant difference in soil pH found in the grazed and control plots, in this study, could be explained by low livestock distributions and effect given that grazing occurs only in summer. The values of pH reported were, however, within the ranges found in other rangeland studies. For example, Ozalp et al. (2016), reported an average pH of 6.55 in pasture lands. Further, acidic soils are common in areas of slow weathering rocks which are typical of the study sites (Arnalds 2015).

The significant difference in soil organic matter in the two habitats (Fig. 4) is likely due to the nutrient additions and other benefits of vegetation to the soil. Vegetation cover aids in the protection of topsoil and accumulation of organic matter through litter fall and decomposition and hence increases nutrient availability. Other studies have reported increased organic matter and nutrients in vegetated areas (Zhao et al 2019), which supports my findings. The low soil organic matter in the gravel desert can also be explained by loss through erosion which is expected in poorly vegetated landscapes. Arnalds et al. (1987) also reported that gravelly surfaces in degraded highland areas generally present low organic matter due to loss through erosion. They further note that the lower layers in these degraded areas have slightly more organic matter, which is consistent with my findings. The organic matter could have been contributed to the lower horizon by plant roots prior to the degradation, or could be remnants of an A horizon of the pre-degraded landscape that was protected from erosion by gravel heaved upon it during numerous winter episodes. More organic matter in the topsoil layer of the vegetated heath can be explained by the short-rooted vegetation in the area restricting movement of SOM to the lower soil layers.

Also, the seemingly higher values of C:N ratios in the fenced as compared to the control plots (Table A1) could be attributed to higher concentration of organic matter inputs in the soil due to reduced soil disturbance and this facilitates the accumulation, storage and mineralisation of carbon in the soil, releasing nitrogen. The difference in the two treatments was not significant, however, and this could be because of the slow processes in tundra ecosystems. Grazing also decreases soil organic matter as herbivores feed on the biomass, reducing both litter and plant cover (Wang et al. 2019). The lower C:N values in the control plots (Fig. 4) could be explained by grazing and trampling effects of livestock which reduce the nitrogen and carbon contents in the soil (Zhou et al. 2017) Studies have also shown higher carbon and nitrogen values in vegetated areas because of litter decomposition (Li et al. 2018) and this could explain the higher C:N ratios in the heath.

5. CONCLUSIONS

This study showed that short-term grazing exclusion had no effect on the chemical soil properties tested. Still, the values of the parameters studied, especially for the fenced plots, showed potential regarding improvement in soil quality. However, the period from exclusion of grazing to the time of field sampling could have been too short to detect any effects of grazing exclusion, given that processes in the tundra region are generally slow. Longer term studies ought to be conducted to be able to report on the optimal exclusion duration and time thresholds for Icelandic rangelands. Such studies would provide valuable information on the conservation and use of these common grazing lands to a nation. Similarly, some of the conclusions of this study could be applied to restoration challenges in Uganda. For example, being able to estimate how long it would take for soils to recover after an intervention like exclusion would be very useful for assessing the practice in the two countries.

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APPENDICES

Table A1: Comparison of mean values of soil pH, organic mattercontent (SOM) and C:N ratios in control (grazed) plots at Audkuluheidi and Theistareykir. Mean values and standard deviations are shown.

		Site		
	Depth (cm)	Audkuluheidi	Theistareykir	p-value
pH	0-10	6.78 ± 0.20	6.54 ± 0.33	0.054
SOM (%)	0-5	9.23 ± 4.38	10.61 ±7.26	0.58
	5-10	7.66 ± 2.91	7.87 ± 4.17	0.69
C:N ratio	0-10	15.92 ± 1.48	16.93 ± 3.15	0.45

Table A2: Comparison of soil pH, organic matter and C:N ratio in control (grazed) plots in the two habitats, gravel desert and heath. Mean values and standard deviations are shown.

		Habitat		
	Depth (cm)	Gravel desert	Heath	p-value
pH	0-10	6.84 ± 0.19	6.48 ± 0.24	0.001
SOM (%)	0-5	4.75 ± 2.11	15.09 ± 9.28	0.001
	5-10	6.04 ± 5.51	10.82 ± 1.81	0.001
C:N ratio	0-10	14.65 ± 2.98	17.51 ±1.91	0.003

Table A3: Comparison of mean values of soil properties at 0-10 cm using a t test between the two treatments, control and fence.

		Treatment		
	Depth (cm)	Control	Fence	p-value
pH	0-10	6.67 ± 0.29	6.53 ± 0.30	0.84
SOM (%)	0-5	11.2 ± 2.38	9.8 ± 2.19	0.44
	5-10	8.2 ± 2.72	7.4 ± 2.33	0.45
C:N ratio	0-10	16.08 ± 2.41	17.09 ± 2.98	0.13